Statistical models of altitude distribution of temperature, humidity, and wind for the atmospheric boundary layer of Western Siberia

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The paper describes the objective classification procedure of climates of the atmospheric boundary layer and climatic regionalization performed using the area of Western Siberia as an example. Four homogeneous areas were revealed for winter period and four areas were revealed for summer period. For each area the local statistical models were constructed. These models include the model profiles of altitude distribution of mean values, root-mean-square deviations, and matrices of interlevel correlation of temperature, mass part of vapor, zonal and meridian wind.

It is known that in solving different problems of atmospheric optics and remote sensing of the atmosphere the statistical models of altitude distribution of meteorological values have found wide application. These models, however, up to now have been mainly created for the free atmosphere (see, for example, Ref. 1) and did not relate to the atmospheric boundary layer. Taking into account this fact, the authors of this paper tried to compensate for such a gap, having developed the procedure of an objective classification of climates of the atmospheric boundary layer and climatic regionalization, as well as construction of local statistical models realized using the region of Western Siberia as an example. Below we describe this procedure and results of its realization.

The procedure of objective classification reduces to division of some objects of X_l ($l = 1, 2, ..., L$) into classes in the k-dimensional space of description E in accordance with the information characteristics N_q ($q = 1, 2, ..., Q$) and the given degree of similarity. In our case, for classification of climates of the atmospheric boundary layer, performed by the complex "temperature – humidity – zonal and meridian wind," as characteristics of N_q we used:

– the mean (climatic) profile of altitude distribution of the meteorological value $\mathbf{m}_\xi^{(k)}$ representing k-dimensional vector, whose components are discrete values $m_\xi(h_k)$ at different heights h_k (at $k = 1, 2, ..., K$);

– basic eigenvectors F_α and eigenvalues λ_α (here α is the number of expansion value) of a partitioned normalized correlation matrix $\boldsymbol{\mu}_x$, whose units, positioned at the principal diagonal, represent the autocorrelation matrices of temperature $\|\mu_{tt}\|$, humidity $\|\mu_{qq}\|$, zonal $\|\mu_{uu}\|$ and meridian $\|\mu_{vv}\|$ winds, and the rest of units are the appropriate reciprocal functions of the correlation matrix; in this case

$$\|\mu_{tq}\| = \|\mu_{qt}\|^{\mathrm{T}}, \quad \|\mu_{tu}\| = \|\mu_{ut}\|^{\mathrm{T}}, \quad \|\mu_{tv}\| = \|\mu_{vt}\|^{\mathrm{T}},$$

$$\|\mu_{qu}\| = \|\mu_{uq}\|^{\mathrm{T}}, \quad \|\mu_{qv}\| = \|\mu_{vq}\|^{\mathrm{T}} \text{ и } \|\mu_{uv}\| = \|\mu_{vu}\|^{\mathrm{T}},$$

where T is the operator of transposition.

At the same time, as degree of similarity, used for selection of boundaries of homogeneous areas with different temperature – humidity and wind regimes, three statistical criteria were used.

In particular, to compare the proximity of mean profiles, obtained for two stations l and s (at $l = s = 1, 2, ..., L$) the criterion of similarity of species is taken:

$$\bar{r}_{ls}^{(m)} \geq r_{\mathrm{crit}}^{(m)} = \tanh z_{\mathrm{crit}}. \tag{1}$$

Here

$$\bar{r}_{ls}^{(m)} = \Big(\sum_{1}^{4} r_{ls}^{(\xi)}\Big)/4,$$

in this case

$$r_{ls}^{(\xi)} = \frac{1}{\sigma_l \sigma_s}\left(\frac{1}{k}\sum_{i=1}^{k} m_i^{(l)} m_i^{(s)} - \bar{m}_l \bar{m}_s\right),$$

where $\bar{m}$ is the mean layer-by-layer value for each of four taken meteorological values obtained by averaging all the k-components (level values) of $\mathbf{m}_\xi^{(k)}$; σ is the root-mean-square deviation characterizing variations of k-th components of the same vector relative to mean layer-by-layer value m; $z_{\mathrm{crit}} = 3\sigma_z$ is the critical value of the Fisher function (at $\sigma_z = 1/\sqrt{k-3}$ and $k = 10$, determined by the volume of sample, i.e., by the dimension of compared vectors of mathematical expectations), the use of which enables one to find easily the value of the critical criterion $r_{\mathrm{crit}}^{(m)}$ by means of special tables[2] (in our case it equals 0.812).

To assess the similarity of eigenvectors of generalized correlation matrices, obtained for two compared stations l and s, we applied the criterion of stability of these vectors of the type:

$$\bar{r}_{ls}^{(F)} = \left[\left(\sum_{\alpha=1}^{p} r_{\alpha}^{(ls)} \lambda_{\alpha} \right) \Big/ \sum_{\alpha=1}^{p} \bar{\lambda}_{\alpha} \right] \geq r_{\text{crit}}^{(F)} = \tanh z_{\text{crit}}, \quad (2)$$

where

$$r_{\alpha}^{(ls)} = \sum_{i=1}^{k} F_{\alpha i}^{(l)} F_{\alpha i}^{(s)} = \cos(F_{\alpha i}^{(l)}, F_{\alpha i}^{(s)})$$

is the coefficient of similarity of two k-dimensional eigenvectors $F_{\alpha}^{(l)}$ and $F_{\alpha}^{(s)}$, calculated for l-th and s-th compared unit matrices μ_x; $\bar{\lambda}_{\alpha} = (\lambda_{\alpha}^{(l)} + \lambda_{\alpha}^{(s)})/2$ is the arithmetical mean from the eigenvalues of one and the same number α; p is the number of used for classification terms of expansion (we set $p = 5$ because more than 90% of the net dispersion are due to the first five eigenvectors); $z_{\text{crit}} = 3\sigma_z$ is the critical value of the Fisher function (at $\sigma_z = 1/\sqrt{n-3}$ and the order of matrix μ_x $n = 4k = 40$), which makes it possible to find using special tables[2] the value $\bar{r}_{ls}^{(F)}$, which in our case equals 0.456.

And, finally, to assess the significance of divergence of norms of generalized correlation matrices λ_{α} (at $\alpha = 1$), which are the dispersions of the entire space (i.e., the entire considered atmospheric boundary layer) the Kokhran criterion[2] was used:

$$G = \left(S_j \Big/ \sum_{l=1}^{L} S_l \right) \leq G_{0.05}(f, L), \quad (3)$$

where S_j is the largest norm of the matrix μ_x from L compared ones; L is the number of norms; $G_{0.05}(f, L)$ is the critical value of the Kokhran criterion determined at 5% level of significance for the number of degrees of freedom $f = n - 1$ (here n is the order of matrix μ_x, which equals 40), and a given number of matrices L comparable with the use of a special table[2] (in our case, $G_{0.05}(f, L)$ at $f = 39$ and $L = 8$ is 0.201).

When the following conditions are fulfilled

$$\bar{r}_{ls}^{(m)} \geq r_{\text{crit}}^{(m)}, \ \bar{r}_{ls}^{(F)} \geq r_{\text{крит}}^{(F)} \text{ and } G \leq G_{0.05}(f, L) \quad (4)$$

all the comparable mean profiles, eigenvectors and matrix norms μ_x, calculated for the stations l and s, are the homogeneous areas, where the fields of temperature, humidity of air, zonal and meridian winds agree from the statistical standpoint and are homogeneous relative to synoptic and mesoscale processes.

To realize the procedure of objective classification of climates of the atmospheric boundary layer and climatic regionalization of the territory of Western Siberia, the authors used the long-term (2001–2005) observations of the work of eight aerological stations: Salekhard (66°32′N, 66°40′E), Turukhansk (65°47′N, 87°56′E), Khanty-Mansiisk (61°01′N, 69°02′E), Aleksandrovskoye (60°26′N, 77°52′E), Verkhnee Dubrovo (56°44′N, 61°04′E), Omsk (54°56′N, 73°24′E), Novosibirsk (54°58′N, 82°57′E), and Emel'yanovo (56°11′N, 92°37′E), in this case the data, presented at standard isobaric surfaces and levels of special points, are reduced to the system of geometric heights: 0, 100, 200, 300, 400, 600, 800, 1000, 12000, and 1600 m.

The objective climatic regionalization of the territory of Western Siberia, realized by the temperature – humidity and wind regimes of the atmospheric boundary layer, is supplemented by the previously performed complex climatic regionalization of the northern hemisphere,[1] according to which during both seasons the Western Siberia is located at the territory of one quasi-homogeneous region. In winter this is a quasi-homogeneous region 2.2 and in summer this is a quasi-homogeneous region 2.4.

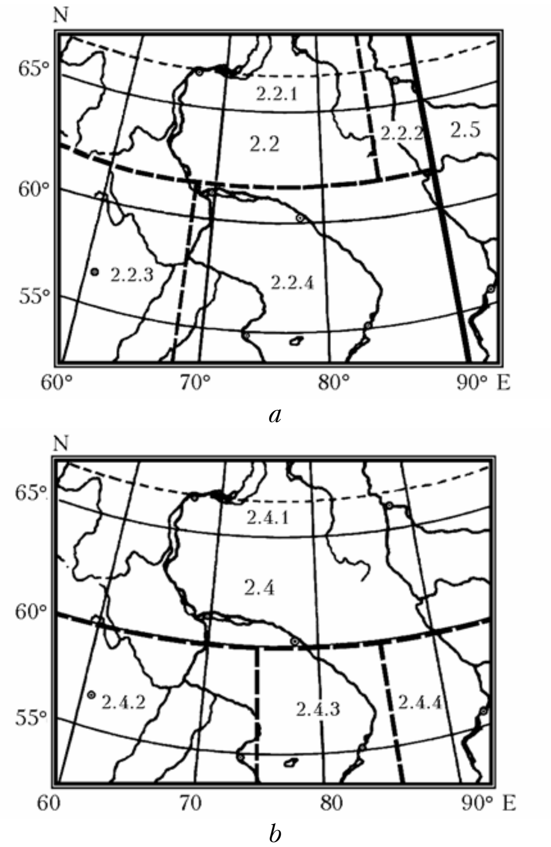

Fig. 1. Climatic regionalization of the territory of Western Siberia based on the regime of the Atmospheric boundary layer, winter (*a*) and summer (*b*).

Starting from the conditions (4), all the territory of Western Siberia, as is shown in Fig. 1, was subdivided (according to the regime of the atmospheric boundary layer) into the limited number of homogeneous subregions (4 – in winter and 4 – in summer).

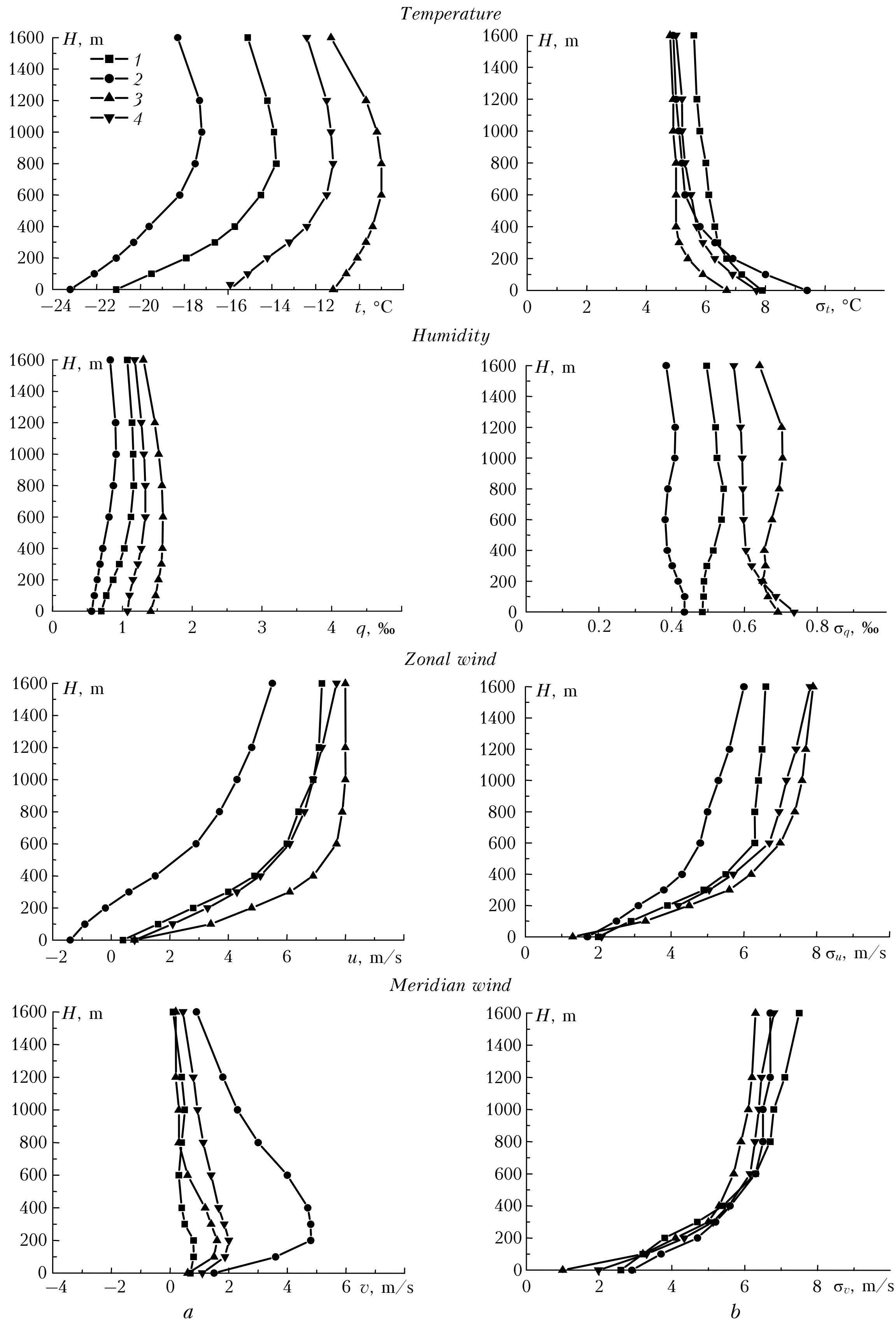

Fig. 2. Local models of altitude distribution of mean values (*a*) and standard deviations (*b*) of the temperature, air humidity, zonal and meridian winds in the atmospheric boundary layer for different homogeneous regions of Western Siberia: *1* – 2.2.1; *2* – 2.2.2; *3* – 2.2.3; *4* – 2.2.4. Winter.

For each such region the constructed local statistical models included: model profiles of altitude distribution of mean values $\bar{\xi}(h_k)$ and rms deviations $\sigma_{\xi}(h_k)$ of temperature (t,°C), mass fraction of water vapor (q, %), zonal (u, m/s) and meridian (v, m/s) winds, as well as model matrices of interlevel correlation $\|\mu_{ij}\|_{\xi\xi}$ of the same meteorological values. It should be noted that because of large body of statistical data, only the model profiles $\xi(h_k)$ and $\sigma_{\xi}(h_k)$ for the winter period are given in Fig. 2 as an example.

References

1. V.S. Komarov, *Statistics in the Application to Problems of Applied Meteorology* ("Spektr," Tomsk, 1997), 256 pp.
2. L.Z. Rumshinskiy, *Mathematical Processing of the Experimental Results* (Nauka, Moscow, 1971), 192 pp.